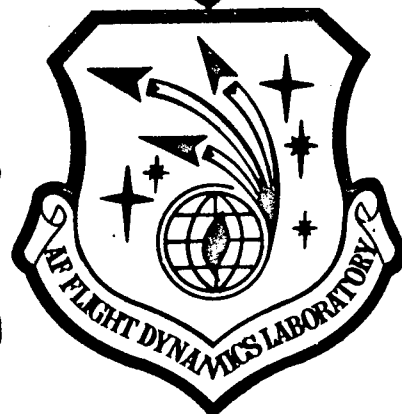


FBR 5845

TM-73-126-FBR

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**SYNTHESIS OF HOLOGRAPHIC INTERFEROMETRY AND SPECKLE
PHOTOGRAPHY TO MEASURE 3-D DISPLACEMENTS**

FRANK D. ADAMS

GENE E. MADDUX

TECHNICAL MEMORANDUM 73-126-FBR

SEPTEMBER 1973

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FOREWORD

This work was conducted by Dr. Frank D. Adams and Mr. Gene E. Maddux of the Analysis Group under Task 146702 "Thermoelastic Structural Analysis Methods", Project 1467 "Structural Analysis Methods", at the Air Force Flight Dynamics Laboratory. Mr. Robert M. Bader is the Technical Manager of the Analysis Group.

The manuscript was released by the authors in September 1973.

This technical memorandum has been reviewed and approved.



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ABSTRACT

Double-exposure "image-plane" holograms made with a reference to object intensity ratio less than unity can be used to measure three dimensional displacements on nearly planar subjects. Holographic interferometry is used to determine the normal displacement component. Speckle photographic techniques are employed to obtain the in-plane components.

INTRODUCTION

The number of articles published in technical journals in the past five years relating to holographic interferometry leaves little doubt that this technique is now a viable tool for doing experimental stress analysis. Yet, holographic interferometry has never lived up to early speculations concerning its potential. This is mainly due to the complex data reduction schemes required to measure general three dimensional displacements (Reference 1). Holographic interferometry is particularly well suited for determining normal displacements on a planar or nearly planar structure. Complexities arise when the in-plane displacement components are desired. This situation has prompted some experimentalist to supplement holographic techniques with other measuring methods. For example, we have been working since 1971 with several techniques involving laser speckle photography. These techniques first introduced by Leendertz (Reference 2) and expanded upon by others (References 3, 4, 5, 6) are particularly well suited for measuring in-plane displacements.

On several occasions, we have determined three dimension displacement fields on nearly planar structures by using both holographic interferometry (normal) and speckle photography (in-plane) in tandem. Since two separate photographic systems were required to obtain both a hologram and a specklegram, the test setups were rather bulky and required more than the usual amount of optical paraphernalia.

These experiences induced us to devise a technique for storing both a hologram and a specklegram on a single photographic plate. The purpose of this report is to describe this new technique.

BRIEF REVIEW

With holography, the interference produced at the intersection of an object wave and a reference wave is stored on a photographic plate. Playback is then accomplished by illuminating the developed photographic plate with the reference wave alone. Diffraction from the grating-like pattern recorded on the photographic plate reconstructs the object wave and thus produces a holographic image. Displacements can be measured by using a double-exposure technique. Exposures are made on one photographic plate before and after a small displacement of the object has occurred. The reconstructed wave is, thus, a superposition of two object waves which interfere and generate fringes over the holographic image. These fringes are interpreted to measure displacements.

A double exposure routine may also be used with laser speckle photography to measure in-plane displacements. A photographic image made using this technique has each speckle recorded twice. The distance between speckle pairs is directly proportional to the local in-plane displacement. Data may be extracted from these specklegrams by illuminating a local area of the image with a small diameter laser beam and observing Young's fringes which modulate the diffraction halo. These fringes are perpendicular to the displacement vector and have a spacing inversely proportional to the displacement magnitude. Other methods of extracting displacement data from specklegrams are discussed in references 2, 3, 4, 5, 6 and later in this report.

SYNTHESIS OF METHODS

The optical and photographic configuration employed to make holograms differs from that used to make a specklegram in two ways. First, with holography, a portion of the laser beam is usually separated from the illumination beam train and directed onto the photographic plate to serve as a reference beam. Only an illumination beam is required for speckle photography. Second, no imaging lens system is required to make a hologram while speckle photography is essentially an imaging process.

Although there is no requirement to use an imaging lens to produce a hologram, such a device is not precluded from the optical setup. Holographers often use imaging lenses to magnify the subject or to relocate it to a different position. In fact, one special form of this technique is called image-plane holography. A lens is used, to image the subject directly on a film plate. During reconstruction a real holographic image is generated in the film plane. A virtual image (also in the film plane) can be observed by using a conjugate reference beam in the usual manner.

The above discussion indicates that the essential difference between image plane holography and speckle photography is the reference beam. This prompted the authors to interrogate a few double-exposure, image-plane holograms with a small diameter laser beam and

to look for Young's fringes. We were at first disappointed to find none but upon further examination reasoned that this should be the case. We normally use a reference wave to object wave intensity ratio of at least 2 to 1. Thus, the exposure variations due to speckle in the object wave were very small.

The reason for using a high reference to object beam ratio in holography is to suppress noise generated from higher order diffraction during wavefront reconstruction. Since the spatial information in an image-plane hologram is already localized, this type of noise is not present.⁷ We, therefore, made several double-exposure image-plane holograms with beam ratios less than unity. This caused large variations in the local exposure due to speckle. Upon interrogation of the image with a small diameter laser beam, Young's fringes were found to modulate the diffraction halo. These fringes possessed contrast as good as any we have seen using normal speckle photography. In addition, no degradation was noted in the holographic reconstruction with reference to objective intensity ratios in the range of 0.6 to 0.1. With ratios larger than 0.6, the visibility of Young's fringes is decrease. With ratios smaller than 0.1, the reconstruction brightness of the holographic image is lessened.

Ordinary speckle photography is restricted to nearly planar test objects unless special optical methods are used. This same restriction is true when employing the new technique and is related to the image

depth of field. By using a smaller lens aperture the depth of field can be increased, however, this also increases speckles size. The result is a decrease in the sensitivity of the speckle photographic method and loss of resolution in the holographic image.

In the second section of this report it was noted that several other methods of extracting in-plane displacement data are used in speckle photography. Most of these involve optical "Fourier" type transforms of the photographic image. The resultant is an image with a fringe pattern superimposed on it. We have tried several of these data extraction methods using our new technique. No degradation of results could be detected as compared to using standard specklegrams.

SUMMARY

A method for measuring three dimension displacements can be synthesized from image plane-holography and speckle photography. The technique involves making a double-exposure image-plane hologram using a reference to object beam ratio which is less than unity. Fringes on the reconstructed holographic image are used to determine one displacement component (usual normal to the object surface). In-plane displacements are measured using any of the methods normally employed in speckle photography.

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